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Psychophysiological Concomitants of Levels of Cognitive Processing.

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**PSYCHOPHYSIOLOGICAL CONCOMITANTS OF LEVELS OF COGNITIVE
PROCESSING**

The Louisiana State University and Agricultural and Mechanical Col. **PH.D. 1982**

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Psychophysiological Concomitants of
Levels of Cognitive Processing

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
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in partial fulfillment of the
requirements for the degree of
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by

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ABSTRACT

The peripheral electrophysiological manifestations of levels of cognitive processing and memory performance were investigated by recording heart rate, skin conductance, skin temperature and electromyogram measures during a three phase verbal task. Subjects processed words at three cognitive levels (phonetic, low semantic, high semantic), and physiological recordings were made during cue covert processing and verbalization phases. Three colored lights were used to cue subjects to the appropriate processing level for each word. An incidental memory task was given following the processing tasks. As expected, words processed at the higher cognitive levels were recalled better. There was greater physiological reactivity associated with the phonetic tasks during the cue phase, while the semantic tasks produced more reactivity during the covert processing and verbalization phases. The high and low semantic tasks were psychophysiologicaly differentiated, the more semantically complex task eliciting greater arousal. An analysis of recalled versus non-recalled trials indicated greater heart rate and skin conductance increases on trials that were later recalled. A multivariate regression of physiological reactivity on memory scores showed a moderate relationship, with heart rate contributing the most variance. The results were interpreted as demonstrating a definite relationship between the level of cognitive operation and the amount of physiological reactivity. The greater activation accompanying the higher processing levels seemed to reflect the degree of cognitive effort at these levels. The reactivity accompanying the cue was interpreted to reflect arousal associated with task expectancy.

INTRODUCTION

The relationship among the physiological, behavioral and subjective components of "mental" experience, especially cognition, has been the subject of much speculation. Attempts at delineating this relationship have encountered immense difficulties, in part because there has been a lack of consensus as to what processes are involved in cognition. The complexity of behaviors subsumed under the concept of cognition is undoubtedly the reason for these difficulties. In the present study, cognition refers to those central nervous system (CNS) functions involved in the processing of information. Information processing includes both operations performed on or as a result of incoming afferent stimuli, as well as operations associated with memory. Within this framework, cognition encompasses a wide variety of CNS activities ranging from sensory registration to the complex processes involved in problem solving and the generation of new responses from previously learned information. Obviously, a tremendous number of different physiological mechanisms could be involved in the various aspects of information processing.

Historically, a common belief prevailed that the higher cortical functions involved in cognition were beyond the scope of physiological study. This belief was justifiable in light of the limitations of previous technology. Physiological psychology was often limited to the study of basic, understandable learning phenomena in lower animals, such as habituation, classical and operant conditioning. While the investigations were essential in establishing fundamental principles guiding brain-behavior relationships, they were unable to address the more complex aspects of information processing. Given that direct physiological investigation of higher cognitive processing in non-humans was

futile, because of the impossibility of self-report, there was a need to develop ways of studying the physiology of human cognition. The use of human subjects solves the problem of self report, but ethical considerations prohibit the exposure of humans to the direct physiological measurements used in animal studies. The advent of electrophysiology was particularly important, since it entailed non-intrusive means of studying the bio-electrical activity of the nervous system, and ANS controlled peripheral organ systems. While the early psychophysiological empirical research was crude and plagued by problems related to technical limitations (e.g., Angell & Thompson, 1899), a foundation was created for studying brain-behavior relationships and some physiological aspects of cognition.

Until recently, there have been surprisingly few empirical investigations relating psychophysiological findings to the various phenomena observed in human learning and memory research. Besides the conceptual and technological problems already mentioned, a number of factors may account for the lack of research in this area, including the fact that few researchers have been interested or knowledgeable in both cognitive and physiological issues. Probably a more important reason, though, was that there was an inability to adequately operationalize and define cognitive processes in a way that would be consistent with concepts originating from the physiological and animal learning studies on which psychophysiology is based.

Despite the difficulties encountered in the psychophysiological study of cognition, there is growing evidence that autonomic and central nervous system activity measured electrophysiologically reliably reflects basic cognitive processes. Therefore, there is a need for additional research investigating the electrophysiological concomitants

of cognition. Such research may help to delineate some of the physiological mechanisms underlying cognitive processes. In the following review, the problems encountered in previous attempts in this area are explored. A research design is developed that may aid in differentiating the components of physiological arousal found during several stages of information processing in tasks varying with respect to the required level of processing (Craik & Lockhart, 1971).

Psychophysiological Arousal and Emotion

The predominant finding in the early studies of the electrophysiological concomitants of "mental experience" was an increased electrophysiological response relative to baseline levels when various cognitive motor tasks were performed. For instance, Woodsworth (1940) and Pillsbury (1908) demonstrated galvanic skin response (GSR) activation, as well as changes in other vegetative responses such as heart rate, during problem solving tasks. The problem solving tasks required verbal solutions to mental arithmetic problems, as well as some more complicated, classical problem-solving situations (Dunker, 1945; Maltzman, 1955). While these findings do not seem remarkable in light of current psychophysiology, a formulation was established for understanding the relationship between cognitive behavior and psychophysiology. The increased physiological activity occurring during cognitive tasks was seen as a generalized form of arousal. Therefore, psychophysiological arousal was defined by the occurrence of increased electrophysiological activity. Researchers generally concluded that autonomic nervous system (ANS) arousal accompanies performance on a variety of cognitive tasks.

Subsequent research has further implicated the role of ANS arousal

in problem solving tasks (e.g., Tikhomirov & Vignogradov, 1970).

Tikhomirov and Vinogradov (1970) monitored verbal response during chess problem solving, and found increased GSR to be associated with response activation. However, as in early studies, there was no way of determining whether the ANS arousal was actively associated with the emotional excitement as Tikhomirov and Vinogradov suggested, or with the attentional demands of the situation. Hence, conclusive determination of the components of cognitive processing reflected in ANS arousal could not be made from this study.

An important factor contributing to the inability of studies to differentiate among the various components of cognitive processing was that many studies, (e.g., Woodworth, 1940; Pillsbury, 1908) lacked a systematic investigation of electrophysiological response as a function of task parameters: there was insufficient consideration of how changes in task demands affected electrophysiological response. Also, early studies tended to focus on a single electrophysiological response, rather than on a response system or the interaction among systems (pattern) when evaluating the electrophysiological effects associated with particular stimulus conditions and attendant cognitive processes. Consideration of single physiological responses may result in a failure to detect small differences in the relationship among physiological systems. Given the fact that a single electrophysiological response can occur to a multitude of stimuli and given the holistic, organismic (systems) functioning of the CNS, patterns of response became very significant.

As noted previously, emotion has been considered central to the ANS arousal accompanying cognitive tasks. James (1884) considered emotional experience to be a function of the perception of afferent

feedback from peripheral organ systems. Emotion was believed to reflect the physiological activation occurring in differential response patterns related to the nature of the stimulus condition. Other theories of emotion (Cannon, 1927; Duffy, 1962, Schachter & Singer, 1962) have considered the physiological activation to be undifferentiated, with respect to emotional content. Central cognitive processes were postulated to account for the subjective differentiation of emotions. The position of Cannon represented an important distinction from the view held by James. A critical issue centered on whether peripheral activation was seen as a monolithic occurrence in response to stimuli, or as a pattern of responses that would vary depending on the nature of the emotional context. This distinction raises a question as to whether identifiable peripheral response patterns characterize different emotions. On a larger scale, identifiable peripheral response patterns may reflect differences in the psychophysiological response accompanying the information processing demands of a task.

Considering the historical significance of the argument over the nature of emotional activation (James, 1884; Cannon, 1927), it is not surprising that the first consistent demonstration of psychophysiological response pattern based on the parameter of the stimulus condition was found in the emotional domain. Ax (1953) conducted one of the first studies to indicate differences in the nature of the physiological response patterns related to emotional context. Ax demonstrated different electrophysiological response patterns for anger and fear response.

Physiological patterning thus reflected differences in subjective internal states. There were low correlations among the responses to the

two emotions indicating that the response patterns tended to have high specificity. The between subject variance in electrophysiological response patterns was found to be greater than the within subject variance, suggesting that people have specific physiological response modes (individual-response stereotypy), as well as different response patterns to different emotions (stimulus-response specificity). Ax's findings were important since a complex interaction of various physiological systems relative to differing stimulus situations was implicated. Other studies have supported Ax's findings by demonstrating different ANS response patterning as a function of emotional situations. Lazarus, Speisman, Mordkoff and Davidson (1962) found electrodermal and heart rate increases in subjects viewing a primitive surgical procedure, as compared to subjects viewing an emotionally neutral film. Sternbach (1962) found that different responses were associated with viewing sad and happy scenes. Other researchers have found a variety of ANS responses associated with different emotional stimuli (Averill, 1969; Funkenstein, King & Drolette, 1954). The differential ANS response patterns associated with the emotions of fear and anger, have been related to changes in the levels of norepinephrine and epinephrine (Brady, 1967; Mason, 1972). Differential response patterns accompanying emotional experiences have been demonstrated in a number of studies in which subjects were asked to imagine certain emotional situations (May & Johnson, 1973; Schwartz, 1971; Weerts & Roberts, 1976; Graham, 1972). Hence, the differential response to different emotions appears to be a fairly robust finding, that occurs even in the presence of imagined emotional situations.

Lacey and Lacey (1958) emphasized that various factors affect the nature of the electrophysiological response pattern, and that individual response stereotopy and stimulus-response specificity both play an important role in accounting for an individual's response to different kinds of stimuli. Individual response stereotopy refers to the tendency for an individual to respond with a similar pattern of electrophysiological activity across situations, while stimulus response specificity refers to the fact that different stimulus conditions tend to elicit particular response patterns across individuals. Individual response specificity reflects our individual tendency to respond most with a particular response system, and may account for much of the error variance in studies investigating response patterns across groups of subjects.

Although the finding of Lacey and Lacey (1958) were not conclusive, numerous studies have supported the involvement of stimulus response specificity and individual response stereotopy in a wide variety of contexts (Schwartz, Weinberger & Singer, 1979; Lacey, 1959; Davis, 1957; Davis and Buchwald, 1957; Davis, Buchwald and Freedman, 1955; Engel, 1959, 1960). Recent investigators of electrophysiological response patterns in clinical populations have demonstrated that clinical patients with disorders such as headache may show a different pattern of response on mental arithmetic tasks when compared to non-headache subjects (Cohen et. al., 1978; Cohen et al., in press). While these investigators did not focus on response patterns as a function of the parameters of cognitive processes, they indicated that consideration of the pattern of physiological responses may be more important than the analysis of the amplitude of an individual response by itself.

The concepts of stimulus-response specificity and individual-response stereotypy confirm the importance of viewing psychophysiological arousal as a reflection of numerous interacting organ systems (e.g., motor, cardiovascular and skeletal-muscular systems). Therefore, research aimed at investigating the autonomic and central nervous system components of the arousal accompanying cognitive processes should consider the complex pattern of physiological responses. The early research on the electrophysiological concomitant of cognition (e.g. Woodworth, 1938) failed to consider the role of response patterns.

The study of psychophysiology of emotion has provided an important foundation upon which an understanding of the relationship between electrophysiological activity and cognitive processing can be based. Consideration of emotional arousal has demonstrated that arousal is not a single phenomenon, i.e., there are many types or patterns of arousal. Research on response patterning has suggested that the arousal accompanying various situations must be analyzed with respect to a number of separate, but interacting systems. However, the utility of suggesting that emotional arousal accounts for the physiological activity accompanying cognitive processes is questionable.

Given that emotional arousal is defined as a function of the response of a number of physiological systems, little is gained by suggesting that emotional arousal is the basis for the increased physiological activity during cognition. Such a suggestion results in a circularity of definition, since the physiological activity was used to define emotional arousal. Instead, much could be gained by analyzing how physiological activity changes as a function of the meaningfulness, salience of some other parameter in the situation.

The Orienting Reflex and Attention

The concept of the orientation reaction (Pavlov, 1927) seems to provide an avenue for linking the concepts of arousal to basic mechanisms of learning. Pavlov noted in his early research that when an animal is presented a new stimulus it behaviorally orients in the direction of the stimulus. Pavlov suggested that this orientation allows the animal to deal with the potential outcome that the stimulus may produce, and was often referred to as a "what is it" reaction. Within this simple behavior, a basic framework for the concept of attention was built. Attention was thus defined as a system of physiological and behavioral changes that occur in response to an incoming stimulus, and which direct the animal towards that stimulus. The physiological changes associated with orientation were thought to make the animal more sensitive to incoming information, so as to facilitate necessary action in response to a stimulus. Implicit in Pavlov's argument was the notion that this orientation reflected the saliency of a stimulus.

A number of components of the orienting response have been categorized including an increased sensitivity of sense organs (Sokolov, 1960), changes in the skeletal muscles that direct sense organs, changes in the general musculature with increase electromyographic activity, EEG changes indicative of increased arousal and various vegetative (ANS and endocrine) changes (Lynn, 1966). These vegetative changes included peripheral vasoconstriction, central vasodilation (heart, brain) galvanic skin reactions, respiratory changes and heart rate deceleration. Two forms of orienting response have been described by Sokolov, (1960). The first is a tonic orientation reaction which is characterized by

a response to a stimulus with increased arousal over the entire cerebral cortex which is of fairly long duration and which habituates quickly. The second form of orienting response is a local or phasic type which habituates more slowly than the tonic form and which is a shorter duration response confined cortically to the areas associated with the particular sensory modality.

Sokolov (1963) provided evidence that central attentional factors may be critical to the generalized arousal. Sokolov differentiated between the orienting reaction to novel but moderately intense stimuli and a defensive reaction to intense stimuli. Both responses involve numerous ANS innervated organ system responses including increased skin conductance, peripheral vasoconstriction, increased heart contractile force, skin temperature decline, as well as changes in other responses. The two responses differ though, in that the defensive reaction involves cerebral vasoconstriction, while the orienting response involves cerebral vasodilation. Other researchers (Lacey, 1967; Berg and Graham, 1970; Clifton, 1966; Hare, 1973) have found cardiac deceleration to be associated with mild stimuli and orientation, while acceleration was associated with intense stimuli and defensive responses.

Lacey (1967) attempted to delineate the functional significance of the orienting-defensive reactions, particularly the cardiovascular component. Cardiovascular activity was implicated as a control process for the intake and rejection of incoming information. This control process was hypothesized to influence cortical activity through peripheral ANS feedback to the CNS about the level of cardiovascular activity. The increased cardiovascular activity of the defensive

reaction was presumed to cause increased neural firing of pressure sensitive baroreceptors of the aortic and carotid sinuses. The activity of these systems leads to inhibition of cortical electrical activity and hence presumably of CNS processing. When cardiovascular activity decreases, as in orientation, negative feedback from the baroreceptors decreases and cortical activity increases (Bonvallet & Allen 1963). Therefore, orientation and defensive reactions would be related to central attentional process by which incoming information would either facilitate a readiness for further processing (orientation) or would allow the organism to act defensively if the stimulus is overly intense and threatening. The orienting response is differentiated from the defensive response in that it is associated with the intake of, rather than the rejection of, new information. By creating a state of readiness, the central processing capabilities of the animal are enhanced, so that attention is directed. This directed attention facilitates the processing of additional information or the rejection of additional information that proves to be non-salient. While the process by which orientation regulates the intake or rejection of new information is extremely important, and will be discussed in more detail, it should be noted that some researchers have taken opposition to Lacey's argument about the functional significance of the cardiovascular response. For instance, Obrist, Webb, Sutter and Howard (1970a, 1970b) have argued that cardiovascular activity is dependent on the motor demands of the organism, and that this function of the cardiovascular system far outweighs the importance of the CNS feedback effect. The core of this argument stems from the fact that the heart is basically a pump, subject to cortical control and is primarily concerned with motor activity which

is also ultimately under cortical control.

Jennings, Opton and Lazarus (1971) have provided a third hypothesis about the functional significance of the orienting response, suggesting that stimulus conditions based on factors like stimulus complexity create the attentional demands causing cardiovascular inhibition. Unfortunately, Jennings et al. failed to show how cardiovascular inhibition helps an organism attend to a particular stimulus situation. Consideration of the three positions or the relationship of cardiovascular activity to the attentional demands of a situation reveals that each hypothesis explains some aspect of the relationship, but none of the positions accounts for all of them. Cortical functioning is influenced by cardiovascular activity, but cardiovascular activity is also an accompaniment of the sensorimotor readiness for the task demands on attention (Pribram and McGuiness, 1975). This readiness is influenced by cortical processes. Therefore, a reciprocal relationship appears between the cardiovascular and central attentional control components.

As Jennings et al. (1971) have suggested, stimulus factors, such as complexity, may be an important controlling factor for the orienting response. The role of stimulus factors on attention has been well elaborated by Berlyne (1960), who argued that attention was best studied by considering how various stimulus parameters affect organisms' responses. The characteristics of stimuli eliciting the orientation response have been determined to include: novelty, intensity, color, signal value, surprise, complexity and conflict. Conflict was said to occur in a situation when perceptual discrimination is not involved, but a subject showed an increased physiological response due to the

processing demand of a task. Presumably, conflict involved stimulus saliency on a higher cognitive level. Lynn (1966) has suggested that three basic stimulus situations evoke orientation; novelty, surprise and complexity. Novelty was postulated to include basic perceptual factors such as intensity, frequency and duration. Surprise reflected novelty with respect to the sequence of information, while complexity reflected uncertainty or incongruity with respect to the structural patterning of the stimulus.

The first comprehensive model to suggest a physiological mechanism for the orienting response was advanced by Sokolov, (1960, 1963). The neurological model proposed by Sokolov elaborates the concept of orientation to show the function of stimulus parameters. In general terms, the model proposed that the cortex analyzes incoming stimuli and then initiates either excitation or inhibition of the orienting reflex. The model proposed the following processes: 1) Afferent stimulation proceeds along classical sensory tracts to the cortex and also forwards excitatory impulses to the reticular activation system. 2) Incoming stimuli are compared in the cortex to previously stored memory traces. If a stimulus turns out to be novel or significant, an excitatory impulse is sent to the reticular formation. 3) An orienting response is produced by the nonspecific activation of the reticular formation from the afferent stimuli, and the specific excitation of the reticular formation by the cortex. 4) If the stimulus is familiar or not salient the cortex sends an inhibitory impulse to the reticular formation which inhibits further orientation.

Unfortunately, Sokolov (1963) did not adequately specify the

neural mechanisms underlying his model. The neuronal model presumes that the creation of a stimulus model in the cortex to new stimuli is fundamental to the process of orientation and habituation. The stimulus is used for further comparisons to new stimuli. Orientation occurs when there is a mismatch between the model and the new stimulus. Habituation occurs because a new model is developed and there is no longer a mismatch between stimulus and available models (therefore there is no OR available).

Recently, Sokolov (1975) proposed a mechanism to account for the effects. Sensory stimulation was postulated to activate two classes of hippocampal neurons. With novel stimulation and combined model mismatches, Type A (activatory) neurons are excited and Type I (inhibitory) neurons are suppressed. The suppression of the Type I neurons was thought to cease tonic maintenance of the synchronization systems (sleep). With repeated stimulation, there is no longer a critical model mismatch and Type I neurons show sustained activity, but Type A neurons cease to be excited, resulting in habituation due to decreased excitation of arousal systems and increased excitation of synchronization systems.

There have been numerous animal studies investigating the possible mechanisms for stimulus model representations (Bagshaw, Kimble & Pribram, 1965; Kimble, Bagshaw & Pribram, 1965; Schwartzbaum, 1961; Pribram & McGuiness, 1975). These investigations determined that there were deficits in orientation, habituation and memory when various cortical structures, such as the amygdala, frontal cortex and hippocampus were resectioned. The results from these studies indicated

two important findings: 1) the viscer-autonomic component of the orienting response is essential for habituation to occur. 2) the fronto-limbic forebrain is somehow involved in the production of habituation. Pribram and McGuinness (1975), have argued that these results suggest that orientation and habituation are directly linked to the registration of information in memory, by the influences of the amygdala and frontal cortex. However, it is difficult to determine if the brain structures actually produce memory registration, or whether they act to control the attentional control processes that direct the formation of memory. Therefore, conclusive evidence supporting the neuronal model has not been demonstrated. The actual occurrence of a stimulus model has not been shown. Also, it is difficult to show how the Sokolovian neuronal model accounts for stimulus-specific inhibition of access to higher sensory processing, since activation by the ARAS is thought to be diffuse and thus when it is inhibited or excited, all stimuli input is inhibited or excited. In such a condition, selective attention to one stimulus among many simultaneously present cannot occur.

Groves and Thompson (1970) proposed a "dual-process" model of habituation, which bears upon Sokolov's model of the orienting response in many respects. The dual process model postulates that habituation occurs within the sensory analyzing system, but that a second process of sensitizations occurs which allows the animal to re-orient to changes in the stimulus condition. This sensitization does not cause a specific dishabituation of the sensory systems, but rather a superimposed activation of all systems. This approach differs

from the neuronal model, in that sensitization is seen as a separate process from neural habituation. This distinction is important, since the process of superimposing re-orientation over habituation allows for more complex forms of cognitive behavior.

The "dual-process" model postulates the existence of two types of neurons to account for the separate processes of habituation and sensitization. Type H neurons are interneurons found in the classical sensory pathways. With increased stimulation they decrease firing and cause inhibition of sensory processing. Type S neurons were also postulated, and are found in the ARAS, and they increase firing rate over repeated stimulations which can account for general facilitation through the general activation of the ARAS and hippocampus. The dual process model seems to have strong support from neuro-anatomical studies (Groves & Thompson, 1970).

Recently, Waters and Wright (1979) proposed an habituation/sensitization model of selective attention which incorporates Thompson's dual process model of the orienting response and habituation. Basically, Waters and Wright propose that repetitive unsequenced stimulation results in habituation of the OR and inhibition of higher processing of that stimulus via the actions of type H interneurons in the classical sensory pathway (including primary sensory cortex). Sufficient information may pass through the pathway, however, to enable primitive cognitive processes to occur, e.g., recognition or registration of the stimulus. In addition, early stimulus presentations are processed in an uninhibited fashion such that higher cognitive processing can occur (type H neurons do not inhibit during early

presentations).

If the stimulus is consequential (has, or signals some stimulus that has, effects on the physical integrity of the organism or is novel) limbic-frontal pathways are excited and these add both to general CNS arousal and, most importantly, to facilitation of the specific sensory pathways associated with eliciting stimulus. This facilitation becomes necessary if the stimulus is repeated, since it counters the inhibition generated by the type H neurons in the sensory pathway and thus enables higher cognitive processing. If two or more stimuli are present then, the competition for access to limited higher processing channels is won by the stimulus which has the optimal combination of more consequentiality (and sensitization) and less redundancy (is less often repeated and generates less habituation).

Generalized arousal is seen as occurring via Sokolov's model of hippocampal action upon ARAS and the presence of type S neurons in the reticular portion of the ARAS.

Waters and Wright describe attention essentially as a CNS facilitation process which enables higher cognitive and motor responses to stimulation. The orienting response is a complex of such CNS activity enabling responses and concurrent information processing.

Activation, Arousal and Effort

The concept of attention was defined by early researchers with respect to the stimulus set. The emphasis on stimulus set has much theoretical precedent in the formulations of Broadbent (1958). Broadbent postulated that pre-attentional mechanisms allow simultaneous stimuli to be processed in parallel. A buffer storage area was thought

to maintain information in parallel, until further processing was conducted on each stimulus item in a serial manner. The attention mechanisms postulated by Broadbent involved a filtering process by which irrelevant stimuli or noise was excluded from further processing. While the model suggested by Broadbent had important implications for further developments in information processing theory, there was clearly an emphasis on stimulus set, over response set.

Treisman (1960) developed an "attenuation" model of attention that was based on Broadbent's notion of filtering, but which emphasized response selection. The attenuation model maintains that the information in unattended stimuli can often produce a response and that this effect occurs because the unattended message is degraded, such that the information is reduced. However, consequential stimuli would still be responded to. The attenuation model established the role of consequentiality in determining whether information penetrates the attentional barrier and produces a response activation.

Neisser (1967) offered an alternative model of attention, in which unattended stimuli are thought to be only partially analyzed. Perception was viewed as a process of analysis by synthesis on reconstruction. This reconstruction process occurs only when unexpected stimuli occur. Otherwise pre-attentional mechanisms can analyze simple information. Neisser's model is important since it places ever more of an emphasis on the active nature of attention, as a function of the response to consequentiality.

The theories of attention described by Broadbent (1958), Treisman (1960) and Neisser (1967) vary in the degree to which attention is

seen as an active or passive phenomenon. However, each of these theories argues that the selection of information is based primarily on the physical characteristics of the message. Meaning is extracted only from those signals which are selected. Several "late selection" theories have been generated which view attention exclusively with respect to the response set (Deutsch & Deutsch, 1963; Norman, 1969). These theories maintain that all incoming signals undergo analysis for meaning, but that attention controls the selection, organization and execution of a response. Attention is therefore considered to be linked more exclusively to the response demands of the situations.

Recently, some researchers have taken a more intermediate position, by suggesting a capacity model of attention (Underwood, 1976; Kahneman, 1973). The capacity model maintains that the nature of signals that are analyzed through attention depends on the available capacity for processing. The number of signals that can be processed at a given time will depend on the amount of the capacity conserved for each signal during processing. According to the capacity model there is a trade off between the number of messages that can be processed simultaneously and the amount of information that each message can hold, and that attention is determined by the specific demands of the situation. Therefore, the capacity model represents an attempt to combine stimulus and response set.

Pribram and McGuiness (1975) addressed the problem of viewing attention relative to response set, as well as stimulus set. Three control processes were described for the regulation of central attentional processes: 1) arousal produced by the stimulus relative

to the background of noise, 2) activation of response mechanisms, 3) the coordination of activation and arousal through effort. The three control processes are transactional, which makes empirical differentiation among the processes difficult. Through psychophysiological observation of central and peripheral arousal responses, it is often nearly impossible to determine whether effort, stimulus arousal or response activation is involved.

Two major paradigms commonly have been used to study attention. The first paradigm involves the recording of behavioral or electrophysiological responses to events imposed on a background of monotonous sensory input (orienting, vigilance and habituation). The second paradigm involves the pairing of reinforcing response outcomes with sensory events (conditioning). Unfortunately, these two paradigms have been largely unsuccessful at delineating among the three factors of attentional control. The study of the orienting response and its habituation has provided a means of studying the effect of stimulus arousal, however, consequentiality relative to the response set also seems to be involved in the process.

A basic problem stems from viewing attention as a single entity, rather than a process involving multiple interacting systems (Neisser, 1967). As Pribram and McGuiness (1975) indicated, there are three control processes underlying attention. By viewing attention as a function of a number of interacting physiological systems the components of effort, activation and arousal may be differentiated. For example, the occurrence of patterned response at the cortex during EEG recording suggests that each cortical site can be considered an

information processing channel which is consonant with underlying physiological systems (Neisser, 1967; Kahneman, 1973; Lindsay, 1970).

Neurophysiological evidence points to the involvement of various cortical structures in the control of attention including the limbic system (amygdala, hippocampus, hypothalamus), the frontal cortex, the basal ganglia, and the sensorimotor cortex (Pribram and McGuinness, 1975). These various structures interact to produce patterns of responses that may be reflected in cortical electrophysiological measurements. However, the structures also control a variety of peripheral activities. Sympathetic and parasympathetic responses occur in order to prepare the organism for behavioral action (Abrams et al., 1964). Therefore, cognitive effort, activation and arousal may be accompanied by a wide range of motor responses. Pribram and McGuinness (1975) have suggested that neuromuscular activity is peripheral in its origin, but with increased problem solving, this activity becomes concomitant with the brain processes involved. Thus, the neuromuscular activity, in a sense, becomes cognitive in its own right. Recently, evidence for attentional components in neuromuscular patterning was demonstrated (Cacioppo and Petty, 1981) suggesting that there is much specificity of muscle action underlying the different components of attention.

Thus far, the consideration of cognitive processes has been limited to consideration of the concept of attention. This consideration is essential in linking the concepts of psychophysiological arousal, activation and effort to higher cognitive factors. This linkage is important since attention provides a foundation of processes

upon which an understanding of higher cognitive processes can be built. It is not surprising that the cognitive phenomenon of attention was the first to receive much study, given that attention can be well operationalized with respect to the orientation response, habituation and other processes of arousal, activation and effort. The physiological, biochemical, anatomical and behavioral concomitants of these processes are more easily determined than other cognitive phenomena such as memory.

A plausible argument can be made that the concept of attention, along with the principles of classical and operant conditioning can be used to explain literally all the phenomena that are subjectively labeled as higher cognitive functioning (Pribram and McGuiness, 1975). For instance, Wagner (1976) developed a detailed theory of habituation, which assumes habituation to underly the process of short-term memory. However, there have been many advances in the area of human information processing research which seem to transcend the current state of psychophysiological conceptualization. In particular, the issues related to the encoding, maintenance and retrieval of memory have remained largely understressed in psychophysiological studies. In the following section, some of the current approaches to higher cognitive functions are considered, as well as recent attempts to relate the complex systems of arousal and activation to these cognitive functions.

Higher Cognitive Processes

The theory and investigation of human cognition had historical roots that were quite different from those of psychophysiology. For

this reason, the language used to describe phenomena often varied greatly between the two psychological approaches: Different terminology was used to describe the same phenomena. Further, both approaches avoided addressing certain issues that were not easily subject to operationalization. Psychophysicists failed to address many of the psychological phenomena noted by researchers in the fields of human learning and cognition, while cognitive researchers often avoided the consideration of physiological processes that might underly memory and related phenomena. Added confusion was brought to the arena with the advent of cognitive models, since often such models were created with no attention to the physiological constraints of the human system.

Most of the current theories of cognitive processing have roots in the doctrine of the association of ideas, later elaborated in stimulus-response theory. The stimulus-response learning approach maintains that memory and other cognitive experiences stem from the linkage of two or more stimuli which form associations in a continuous fashion. This associative phenomenon served as the basis for years of investigation in the area of verbal learning, as paradigms neatly showed how verbal material was learned over a series of repetitive trials. While this paradigm provided a powerful mechanism for explaining human learning, most researchers have concurred that the associative mechanism provides only a foundation for other more complex processes, such as memory.

G. Miller (1956) eloquently elaborated on the shortcomings of relying on a strict associative chaining model. Miller provided

evidence to illustrate that simple linear chaining cannot statistically account for the complexity of permutations needed for the creation of even a simple sentence. The necessity for considering additional cognitive mechanisms has become evident in the past two decades. A number of mechanisms have been postulated to explain how more complex phenomena might occur. The concepts of chunking, consolidation and encoding are among the most important of these mechanisms. The concept of chunking was originally formulated by G. Miller (1956), to refer to a learning process in which a "set of associative nodes representing constituents (components, attributes, features)" of a whole stimulus, becomes associated to a new node which subsequently represents the whole stimulus. The new associative node is referred to as a chunk, since it consists of a cluster of constituents of the original stimulus. Consolidation refers to the process by which the chunked node becomes stored as memory. Encoding has been used by Wickelgren (1979) to refer to the process by which the chunked stimulus is neurally consolidated into a durable memory trace. Wickelgren differentiated encoding from chunking by suggesting that encoding refers to the neuronal mechanisms for consolidation of a memory trace, while clustering represents a concept derived from a mathematical model for associative bonding. While the concepts of encoding and chunking were derived from different theoretical perspectives, they seem to describe the same basic mechanism for memory. This mechanism allows for storage of stimulus information, such that the memory trace consists of a network of associates rather than as the stimulus in its original form. Within this framework a node is considered to represent a cluster of cortical neurons, which may

either be locally or generally distributed throughout the brain.

Underlying the concepts of chunking and encoding is the assumption that these processes occur due to an activation gradient across the cortex. Thus a possible (if somewhat crude) neural mechanism for the production of memory and representational logic is demonstrated. If a stimulus is capable of being chunked and encoded relative to a network of constituents of the stimulus, then a particular stimulus could trigger a number of internal channels, rather than one linear chain or responses. Chunking and encoding have been proposed as a basis for concept learning (Wickelgren 1969) and propositional learning (associating concepts to a chunk node representing propositions) (Anderson and Bower, 1973) in semantic memory. Semantic memory refers to a form of memory that is related to meaningfulness of a stimulus or context. Semantic processing is distinguished from phonetic and lower forms of processing in that presumably the lower forms of processing do not require meaningfulness. However, it is obvious that the concept of meaningfulness is subjective. Ultimately, meaningfulness may have to be considered as a continuum rather than a dichotomy of semantic vs. non-semantic tasks.

Despite the explanatory power of concepts such as encoding and chunking, information processing theory has placed less emphasis on the role of associations. Information processing theory tends to focus on memory for items rather than memory of associations. An increased weight was placed on the stages through which information was processed, and on the nature of the processing itself. An interesting example of the difference between the two approaches to

cognition is seen in the interpretation of the act of forgetting. Associationists view the phenomenon as the result of the extinction of associative bonds. Interference is the primary mechanism accounting for such extinction. Information processing theorists define forgetting as the decay of an actual memory trace for an item. Recent evidence seems to suggest that, in fact, both factors are important (Murdock, 1974). However, it is important to note that in both explanations support is based on which model best predicts memory performance, rather than on an attempt to define performance with respect to what is known about the physiology of the CNS.

One of the most important theoretical models of memory has been the two component "storage area" approach to memory function. The memory for semantically (meaningful) processed material has been thought to reflect two types of memory stores: 1) a short term storage capable of holding primarily phonetically coded information over brief time periods and 2) a long term storage for more permanent semantic encoding (Atkinson & Schiffrin, 1968). Short term memory was thought to be the means of accessing long term memory. For a number of years this approach to memory prevailed as a cornerstone of cognitive research.

While the two-component model of memory seemed extremely parsimonious, there were a number of fundamental problems with the approach. Attempts at attaining a clear distinction between the two stores tended to be futile. Also, there were no clear physiological basis for distinction. Probably most important though, the model tended to focus excessively on the notion of a static form of memory, rather than

memory as an active ongoing process, such as postulated by Bartlett (1929) in his theory of working memory. The reason for the static approach to memory probably reflected the ongoing attempts to determine a localized seat of memory registration.

An alternative, more flexible approach to memory was offered by Craik and Lockhart (1972), in the "levels of processing" paradigm. The model tended to describe memory as a working system that could be defined with respect to the depth of processing that an individual engages in a given task. The approach maintains that difference in the time that information will be retained (i.e., long versus short term memory) is dependent on the quality or extent of the encoding operations rather than on the nature of hypothetical storage area. The memory trace can be viewed as a network of encoded information about a stimulus item. The concepts of consolidation and chunking can be seen to have a logical place in this approach, since the quality of encoding can be thought to be related to the consolidation of chunked stimuli, such that a more redundant or extensive degree of chunking may result in more durable memory. Furthermore, the meaningfulness of a task is postulated to be determined by the complexity or extent of encoding associated with a given item. The paradigm provides an interesting linkage between relatively subjective cognitive events such as meaningfulness and quantifiable memory performance.

The levels of processing approach maintains that the short term memory system is somewhat analogous to attention. Information may be retained in short-term memory as long as attention remains fixed upon the stimulus. Long term memory reflects semantic processing involving

the consolidation and encoding of a trace which has received sufficient attention. However, the levels of processing hypotheses does not adequately address the possible mechanism underlying the durability of encoding during semantic processing.

Craik and Lockhart (1972) suggested that the levels of processing effect was related to the meaningfulness of the stimuli to be processed, as well as to the task to be performed. However, meaningfulness seems to be a complex concept which can not be easily operationalized. One can argue with good reason that meaningfulness simply refers to consequentiality or the relevance of a stimulus. Meaningfulness would be determined by the adaptive value or biological importance of the stimuli (or the association of one stimulus with biologically important stimuli). As Waters and Wright (1979) have suggested, consequentiality may play an important part in attention and psychophysiological arousal. Therefore, the heightened memory performance at the higher processing levels may simply be due to the fact that tasks at those levels elicit more attention.

While the levels of processing approach provided an important shift in perspective on cognitive phenomena, there has been much criticism leveled against the approach on the basis that it does not really improve the understanding about mechanics of cognitive processes (Baddely, 1976; Nelson, 1977). As mentioned above, it is difficult to determine whether increased memory performance at high semantic levels is due to the greater elaboration of encoding at those levels, or to some other factor, such as the generalized arousal produced at higher semantic levels. This generalized arousal could be caused by various factors such as the task difficulty or the tendency for more meaningful tasks to draw more attention.

Another major criticism has been that there is much difficulty in obtaining an independent measure to validate the levels of processing theory. The use of memory performance as a gauge of level of processing creates an internally consistent system, which sidesteps the validity issue. However, the problem of validity due to the construction of an internally consistent theoretical system is not unique to the levels of processing approach, since most of the research in the area of memory has been confronted with the problem of external validation. The criticism is unfair considering that the original proposal of levels of processing was not established as a model but only as a way of testing memory performance with respect to a relevant concept, semanticity. Therefore, the proposal of levels of processing theory may have its greatest utility as a paradigm for testing a variety of cognitive phenomena within a "working memory" framework.

The levels of processing approach provides a good paradigm for testing the components of information processing required in the formation of memory.

Cognitive Psychophysiology

As discussed earlier, attempts at relating the developments in the area of cognition to psychophysiological investigations, have been relatively few and far between. Psychophysiological research has generally focused on more operationally definable cognitive phenomena such as attention. However, psychophysiology could obviously provide an external means of validating the adequacy of certain models and approaches to cognitive study. In recent years there has been an upsurge in the number of investigations of this relationship.

One of the first attempts to relate physiological responses to learning performance in a serial position task failed to find a consistent relationship between blood pressure or respiration and memory score (Brown, 1937). However, speed of learning was found to be related to the amplitude of the GSR response. Brown postulated that the effect was due to increased attention to the first and last words on the list. Berry and Davis (1960) found a similar relationship existing with respect to jaw tension during serial learning. Conflicting results were found by Furth and Terry (1961) in that low arousal subjects showed better learning. Obrist (1962) found that intermediate arousal levels were best for learning, as an inverted U shaped curve of learning with respect to arousal was found.

While the findings of Obrist (1962) seem very consistent with much non-psychophysiological data (Hebb, 1955; Malmö, 1959; Lindsley, 1951) there has been a misconception held by certain researchers that no consistent relationship exists between behavioral performance and physiological activity (e.g., Mandler and Mandler, 1962). Mandler and Mandler's conclusion was based primarily on the analysis of a limited number of conflicting studies and appears to have been premature. Numerous studies have support Obrist's finding relative to short-term memory performance (e.g., Kleinsmith and Kaplan, 1963; McLean, 1966; Butter, 1970).

A possible reason that lack of consistent relationship was found may be due to a confusion between tonic changes over the course of learning and phasic changes that occur in response to the processing of a particular item. Kintch (1965) reported that while GSR levels

declined over learning trials, GSRs to each item in a paired associate tasks increased if the item was correctly associated. Kimble (1965) accounted for these results by suggesting that increased attention occurs during the learning of an item, while across the total learning task habituation occurs. This habituation is reflected in lowered GSR amplitudes over the course of the trials. However, Bagshaw, Kimble and Pribram (1965) provided another interpretation of the GSR results, indicating that the registration of information into a neuronal store, rather than attention may be implicated. This interpretation was shown to correspond with data from animal studies. Animals undergoing an amygdectomy lose their ability to register information that is behaviorally useful, even though they continue to habituate and give orienting responses (Pribram and McGuiness, 1975). The amygdala has been postulated to be a critical structure involved in learning, and seems to have an activity that has been related to the orienting response. However, it seems premature to conclude based on the results given by Pribram and McGuiness (1979) that registration rather than attention is effected by the removal of the amygdala. Possibly, the amygdectomy causes a disruption of certain central aspects of attention, without effecting the visceral components of the orienting response, the OR being a complex of CNS and ANS responses.

The conflicting results found on studies of the GSR response during learning may be due to the fact that the response may reflect different components of the cognitive processes involved in learning at different times. GSR may reflect attention (OR) to more salient stimuli. However, GSR may also reflect the effort entailed in the

consolidation of memory into a long term store. Therefore, the opposing findings (Bagshaw, Kimble and Pribram, 1977; Kimble, 1965) suggest that both components account for increased physiological response, and one must determine whether the activity is related to orientation or memory consolidation or both if the OR facilitates and/or accompanies consolidation.

Spense, Lugo and Youdin (1972) found a cardiac deceleration similar to that reported by Lacey (1967) when target words were correctly identified, but no deceleration when there was a failure to identify the target word. Spense et al. suggested that these results indicated the consolidation of the stimuli into long-term memory. However, the lack of deceleration with failure to recognize a target seems to provide as strong an argument for attentional factors being critical in affecting heart rate since the failure to decelerate when a target word was missed would suggest that the response only occurred when a target was attended to. There appears to be no resolution from this study of autonomic arousal and physiology of whether attention or registration (or both) is associated with cardiac and electodermal changes.

As Sokolov (1963) suggested, memory may play a critical role in the attentional process through a matching of current stimulation with a "neuronal model." Such a matching process requires effort, which may account for physiological activity (Kahneman, 1973). Such activity could still not be assumed to be related to the formation of memory.

Cognitive load has often been studied as a means of delineating the roles of attention and consolidation in memory performance (Kahneman and Beatty, 1966). Pupil dilation was postulated as an

index of the amount of information held in short term memory. Dilation was shown to occur towards the end of the period of attention to incoming information, rather than during the initial phases during tasks requiring verbal performance. Active processing or storage of memory was implicated as a basis for this effect. A subsequent study (Kahneman, Turskey, Shapiro, Crider, 1969) provided support for a similar effect of cognitive load and effort in ANS systems during a digit transformation test. However, there have been few other studies relating cognitive load to the consolidation of memory.

A study by Siddle, (1979) has related skin conductance response to the taxonomic domain of cognitive processing. Habituation was generalized from stimulating words to other words in the same taxonomic category. The semantic level of processing was shown to produce greater skin conductance responses, as compared to tasks based on the physical characteristics of stimulus. This finding seemed to support the importance of task meaningfulness with respect to memory registration. The Siddle et al. study did not define a mechanism for the effect of task meaningfulness or for factors related to memory consolidation, though it did elaborate the concept of attention to describe meaningfulness in a high level cognitive task. Yule and Hare (1980) have extended the findings of Siddle et al. to show increased peripheral responses on a number of ANS measures such as heart rate, vasomotor response and blink rate. The results were interpreted in terms of the role of attention and effort in mediating short term memory.

Studies using CNS measures during learning have also generally failed to find a direct relationship to memory performance. Thompson

and Obrist (1964) demonstrated increased fast wave (beta) EEG activity during active learning. They suggested that this activity was associated with variations in attention, rather than memory consolidation. The contingent negative variation (CNV) response has also been shown to relate primarily to the activation produced due to expectancy of an upcoming stimulus rather than consolidation.

Recently, John (1967, 1972) has provided a "statistical configuration theory" of memory which argues that memory consolidation and representation is mediated by common modes of activity across extensive cortical areas. John's argument stems from consideration of the differential patterning of cortical electrical activity during various cognitive tasks. Shucard and Horn (1972) demonstrated significant correlations between positive peak latencies of the visual evoked potential and memory.

In recent study, Sanquist, Rohrbaugh, Syndulko and Lindsley (1980) demonstrated that increases in the amplitude of the event related potential were related to the level of processing required of subjects performing a same-different judgement task (Craik and Tulving, 1957). While this study did not conclusively differentiate the associative process of memory from general attentional demands, a step was made towards separating the different stages of processing with respect to electrophysiological measures and presumably the underlying electrophysiological activity.

While there is mounting evidence that numerous peripheral and central physiological systems are involved in cognitive processes, there is still disagreement as to how these systems relate to the various

components of cognition (i.e., attention and consolidation of memory). Even the concept of attention is often over-simplified, such that often the components of arousal, activation and effort are not differentiated. There has been demonstration that one reason for the confusion in this area may stem from a failure to consider differential patterns of electrophysiological response to different cognitive tasks. Studies incorporating the analysis of patterns of response (Lacey and Lacey, 1967; John, 1972; Cacioppo and Petty, 1981) have illustrated important differences in physiological activity as a function of different task demands. The failure of many studies to address the transactional nature of physiologic responding is unfortunate, considering that such an analysis might provide valuable information about subtle differences in ANS response patterns to higher cognitive tasks, which might in turn be revealing of differences in the CNS processing underlying them.

The present study attempts to determine if differences in electrophysiological response patterns exist in subjects as a function of the type of cognitive task employed or if quantitative differences (amplitude) in electrophysiological patterns exist as a function of cognitive task. Evidence of differential patterns would imply differential physiological processes, while evidence of quantitative difference would imply differential arousal, activation or effort. A further analysis was made comparing the electrophysiological response to cue-warning lights preceding a task, which would trigger a generalized arousal due to the expectation of a particular upcoming task, with the electrophysiological response during the actual cognitive problem-solving portion of the tasks.

A level of processing paradigm, similar to that devised by Craik and Lockhart (1971) was used to develop cognitive tasks varying in complexity. One phonetic task required subjects to produce three rhyme words for each appropriate stimulus word. The level of complexity of the two semantic tasks was established according to criteria used by Bloom (1959) in his taxonomy of cognitive tasks. One semantic task required subjects to define the stimulus word, while the other required subjects to relate the stimulus word to a social issue. The first task corresponds to Bloom's criteria for a low level comprehension task, while the second semantic task coincides with Bloom's criteria for a high level analysis task. Three different colored lights served as warning stimuli to cue the subject to the task to be performed for a given stimulus word.

The general hypothesis in the present study was that a multi-variant analysis of peripheral electrophysiological response patterns would indicate a difference between the generalized arousal occurring after the cue light onset and physiological activity occurring during the cognitive processing stage of the task for each word. Additionally, task elicited response patterns might vary as a function of the level of processing required by each of three task conditions. Finally, quantitative differences in task elicited response patterns might emerge indicating differences among tasks in arousal, activation or effort. A behavioral check on the level of processing was conducted. Memory performance on an incidental memory task following the cognitive tasks should reflect a greater amount of recall for words processed at the higher semantic levels, in accordance with Craik and Lockhart (1972).

A number of possible outcomes might be expected as follows:

1. The pattern of response to the cue light may be the same as that

for the cognitive task, and both may differ across levels of processing. This result would suggest that the cue light was conditioned to indicate the greater processing demands needed for the higher level tasks.

2. If the cue light produces different response patterns, but the cognitive tasks do not vary in pattern, there would be indication that there was no difference in the level of processing patterns, but that differences in preparatory arousal exist.

3. If the pattern of arousal to the cue light does not differ across tasks, but patterns across the levels of processing differ, there would be indications that the processes involved at the various cognitive levels incorporate different physiological mechanisms.

4. If the cognitive tasks produce differences in the amplitude of responses, but not different patterns, there would be indication that the levels of processing effect is primarily related to attentional factors such as cognitive effort, rather than to a different set of processing mechanisms.

5. If the cue lights produce different amplitudes of arousal, but not different patterns, there would be indications of a greater level of expectancy, but not a different mechanism for the different cues.

The above hypotheses were tested utilizing multivariate analysis and multiple regression procedures.

METHOD

Subjects

Thirty UCLA undergraduate psychology students (males and females) served as subjects in the study. The subjects were volunteers receiving course credit for participation. Students ranging from 18 to 30 years of age were selected as subjects.

Apparatus

Physiological signals were processed through a Beckman Type R 8 Channel Dynograph modified for on-line computer use. All responses were recorded using Ag/AgCl Beckman Biopotential electrodes.

The skin conductance response was processed through a Lykken-type constant-voltage coupler to yield DC values and then run through an AC coupler with a time constant of 1 sec. and a constant voltage (.5v). Heart rate was sampled every .1 sec and beats per second was determined automatically by the computer system. EMG was integrated using two Med Associates (9852A) Averaging couplers.

A Digital Equipment Corporation PDP-11/GT-40 computer using a TR-11 operating system and Basic RT-11 programming language controlled stimulus presentation, data processing and data storage. Subjects sat in a 3.3 meter by 2.1 meter sound attenuated room with monitoring and recording equipment in a separate room. Visual presentations were made using a Kodak slide projector with a tachistoscopic shutter control.

Psychophysiological Recording

Continuous recordings were made during all phases of the session. The following measures were obtained from each subject: heart rate (HR), electromyographic activity (EMG), skin conductance (SC), and

skin temperature (ST).

Heart rate was recorded from a standard lead II configuration. The threshold comparator sampled the EKG signal every .1 seconds to determine the beats per second.

EMG was recorded from two sites. One site was a standard placement for the frontal muscle. EMG was also recorded at a site on the laryngeal muscle of the neck. Raw EMG activity was integrated using the EMG averaging coupler. EMG in μV was sampled every 1 second and was rounded to .1 μ volt for each 1 second sampled.

Skin conductance was recorded from a left placement of the central palm and eminence. The amplitude of each skin conductance response was recorded. Changes of greater than 1% relative to baseline levels were considered a response. The amplitude of each response was determined in μ mhos.

Skin temperature in degrees centigrade was obtained using a thermistor placed on the index finger of the left hand. Temperature was sampled every second and averages were obtained for each interval.

Stimuli

Three colored slides were used to cue subjects to the type of cognitive operation desired. The cue colors were either red, blue or yellow. The main stimulus material consisted of 39 common one-two syllable nouns selected from the Thorndike-Lorge (1961) list such that each word appears greater than five times in every 100,000 words, but not more than 10 times. Thus each of the 39 words had about the same level of familiarity. Each of the 39 words was selected so that at least three common rhyme words could be determined for a given word. Appendix 1 contains a list of these words.

Procedure

The experiment consisted of three phases: a 5 minute baseline, a cognitive task phase (3 tasks in 30 min) and a memory recall task (10 min.) A five minute rest interval occurred between the cognitive task phase and the recall task.

After signing a consent form, electrodes were placed on the subjects. They then were instructed about the nature of the cognitive tasks and were given an opportunity to learn the type of task to be performed. After subjects exhibited an ability to respond correctly three times on practice trials using the cue lights and 9 test words (3 at each level of processing), they were instructed to relax and sit comfortably with their eyes open for a 5 minute baseline period, after which a verbal instruction would indicate that the cognitive tasks were to begin.

There were three types of cognitive tasks: 1) a phonetic task; 2) a low level semantic task; and 3) a high level semantic task. The 39 common stimulus words were randomly divided among the three task conditions, such that 13 different words were to be used in each of the three tasks. A different colored cue light was associated with each of the tasks, such that a blue light preceded the high level semantic task, a red light preceded the low level semantic task and a yellow light preceded the phonetic task. The phonetic task required subjects to produce as many common rhyme words as possible in response to the stimulus word. The low level semantic task required subjects to give a definition of the stimulus word. The high level semantic task required subjects to briefly discuss an application of the stimulus word, so as to describe how the concept denoted by the stimulus word has impacted on man's attempt to survive, develop or enjoy his life in the modern world.

Subjects performed cognitive tasks on each of the 39 words, such that 13 words were processed at each of the three task levels. The order of presentation of the words and tasks was randomized in an attempt to prevent position effects among the three task levels. The sequence of the cognitive task was as follows: Following the five minute baseline period the first cue light was presented for 7.5 seconds. After this interval the stimulus word was presented for a duration of 7.5 seconds. During the presentation interval, subjects processed the word and derived an answer, but gave no verbal response. Following the offset of a stimulus word, subjects vocalized their answer to the task during a 20 second interval. After this period, a strobe light flashed, which indicated that the subject should stop verbalizing and rest. The rest interval was 20 seconds. After the rest period, the next cue light occurred. Therefore, a total time of 55 seconds was used for each word from onset of the cue light for the word to onset of the cue light for the next word. This same sequence of presentation continued for each of the 39 words.

Following the last presented word there was a five minute rest interval. After the rest interval, subjects were asked to recall and write all of the words that had been presented. This memory task was unexpected by the subjects and therefore constituted an incidental memory paradigm (Craik and Lockhart, 1972). After this task subjects were asked to indicate which of the three tasks was most difficult. The session ended following their answer to this question.

Subjects were given the following verbal instruction: "You will be presented with 39 different common words and you will be asked to perform different mental tasks using the words. Preceding each word

there will be either a red, blue or yellow light. Depending on which light you see, you will perform a different task. A yellow light will indicate that you are to produce as many rhyme words as possible for the upcoming word. A red light indicates that you are to give a definition for the presented word. A blue light indicates that you are to briefly describe the significance of the concept denoted by the presented word. In this task you will indicate the impact that the particular concept has had in man's attempt to survive, develop or to enjoy life in the modern world. For all three of the tasks you will have about 22 seconds to provide a verbal answer to the word. However, you should not begin verbalizing an answer until the stimulus word is no longer visible on the screen. The word will stay on the screen for 7 seconds during which time you should think of an answer. Verbalize your answer during the remaining 20 seconds. When 20 seconds have passed a light will flash indicating that you should rest for another 20 seconds, and await the next flash of colored light which indicates the next task". The randomization of level was controlled so that no more than three occurrences of the same level of task were presented in a sequence.

Design

The independent variables in the study were the level of cognitive task required for a given word (phonetic, low level semantic or high level semantic, as well as the information processing conditions (cue, covert processing, verbalization). Three dependent variables were considered (memory performance, pattern and intensity of electrophysiological activity). Memory performance score was determined by the

number of correctly recalled words from each of three cognitive conditions, and therefore consisted of the percentage correct out of a maximum of 13 words for each task level.

The measure of electrophysiological activity consisted of the amplitude and pattern of peripheral reactivity across various physiological systems during the different parts of the cognitive tasks. Since this reactivity was compared across various phases of the cognitive tasks for each subject, the study utilized a within group design. The reason for using this design was to obtain a more accurate assessment of how an individual's response pattern changed as a function of the physiological measures and data analysis will follow in the next section.

Data Analysis

Change scores were derived for each phase of the cognitive task:

1) The change from level during the 5 sec. before the cue light onset, to level during the first 5 sec. following the cue light onset, 2) the change from levels before the cue light onset to the 5 sec. period following the stimulus onset word of the response, and 3) the change from the level prior to the cue onset to the first 10 sec. interval of the verbalization period.

The change in electrophysiological activity relative to each of these three phases was determined by deriving the average activity for each of the electrophysiological measures during the 5 seconds preceding the cue light onset and subtracting this score from the average activity score for the 5 second period following the cue light onset and preceding the word presentation. Difference scores were obtained which reflected the degree of reactivity for each measure. A similar

difference score was obtained for the change in activity as a function of the cognitive processing of the stimulus word. The average activity for each measure during the 7.5 seconds of stimulus word onset was obtained. These scores were subtracted from the level of activity prior to the cue light onset. Four difference scores were derived for both the cue light interval and the cognitive processing interval, for each of the three task conditions. To obtain average activity scores, activity across the 13 trials pertaining to a given task condition were summed and divided by 13. Thus, for each subject four sets of scores corresponding to the cue light arousal and the three cognitive task performances were derived. See Appendix 3 for a flow diagram of the experimental procedures.

The memory scores from the incidental memory task consisted of percentage correct responses (words correctly recalled from each task divided by 13). The memory scores among the three task conditions were compared via one way analysis of variance to determine if significant differences occurred as a function of the level of processing required in a task.

The electrophysiological reactivity scores were analyzed using a multivariate analysis of variance procedures (MANOVA) to determine if overall differences in physiological activity existed across the three processing levels, or as a function of the phase of processing (cue, covert processing or verbalization). Further univariate analyses of variables was conducted to specify these differences. The laryngeal EMG was analyzed during the verbalization phase to determine the length of the vocalizations on each trial.

An analysis was conducted using a step-wise multiple regression procedure that correlated the electrophysiological reactivity for each subject with performance on an incidental memory task. This procedure was done using standardized (F) score transformations of the four physiological measures relative to each subject's individual mean and standard deviation.

RESULTS

Memory Performance

An initial analysis of memory performance was conducted to determine if the expected levels of processing effect had occurred. There were significant differences among the three levels of processing tasks in number of words recalled, $F(2,58) = 49.56$ $P < .0001$. The order of memory performance was as expected: more words processed at the high semantic level (HSL) were recalled than words processed at the low semantic level (LSL), and both semantic tasks produced better recall than the phonetic level task (PL). The means and standard deviations for the HSL, LSL and PL were 7.86 (1.52), 5.83 (1.70) and 3.93 (1.55) words respectively. A Duncan Multiple Range Test revealed that the three means for HSL, and LSL and PL were all significantly different from each other ($P < .01$). Since the expected memory effect occurred, analysis of the physiological responses during the three tasks could be conducted and interpreted in the context of levels of processing.

Task Difficulty

All subjects indicated which processing task they found most difficult. Their choices were based on subjective impression. Interestingly, the phonetic task was rated as the most difficult by a majority of subjects, $\chi^2(2) = 20.6$, $p < .01$. The percentage of subjects rating each level as the most difficult was as follows: HSL = 26%, LSL = 4%, PL = 70%.

Psychophysiological Measures

Four of the dependent measures (Heart Rate, HR; Skin Conductance, SC; Skin Temperature, ST; and Frontal Electromyogram, EMG.) were analyzed across the three phases of task presentation (cue, covert processing

and verbalization (and across the three task levels (HSL, LSL, PL) within each phase. An additional measure, laryngeal EMG, was analyzed during the verbalization phase (response to information processing task) to determine the average length of a subject's answers during the three task levels.

Verbalization Duration. The laryngeal EMG produced a large amplitude response at the beginning of verbalization which continued until a subject ended his/her response. There were no differences in the average verbalization duration for the three levels, $F(2,58) = 1.58 > P > .05$. The average length of the verbalizations were as follows: HSL = 9.5 sec., LSL = 8.2 sec., PL = 9.2 sec.

Trial Effects. Since there were 13 word presentations at each of the three processing levels, a Multivariate Analysis of Variance (MANOVA) was conducted to determine if psychophysiological reactivity varied across trials. MANOVAs using the four dependent measures (HR, SC, ST and EMG) were conducted for the cue, covert processing, and verbalization phases. There were no significant trial effects for either the covert processing ($F(12,348) = 1.75, p = .14$) or the verbalization phase ($F(12,348) = .67, p = .76$). There was a significant trial effect for the cue phase ($F(12,348) = 10.1, p = .02$), reflecting a decrease in overall physiological reactivity over trials (habituation). Habituation thus occurred during the cue presentations, but not during information processing or during verbalization. Appendix 2 contains a list of centroids for each task level across the 13 trials.

Psychophysiological Reactivity Averaged Across Trials

The lack of a significant trials effect for the covert processing and verbalization phases, indicated that no particular word (trial)

was more arousing than any other. Thus, averaging of trials could be carried out. The trials effect for Cue was clearly a habituation effect, also not attributable to a particular word (trial). Averaging reduced the size of the analysis and made statistical manipulation more feasible. Also, averaging reduced the effect of random fluctuations in response occurring on particular trials.

A MANOVA was conducted to compare the three processing levels (HSL, LSL, PL) across the three conditions (cue, covert processing, verbalization). Table 1 contains a summary of the effects found in this analysis.

As predicted there were significant main effects for Level of processing and Condition. There was also a significant Condition x Level interaction indicating that the amount of physiological activity occurring with the different levels varied depending on the phase of information processing (condition). The Condition x (Score) dependent measure, Level x Score and Level x Condition and x Score interactions were all highly significant, suggesting that the relationship of the physiological variable to one another changed depending on the condition and level of processing, thus indicating that there was the possibility of patterning of responses.

Given the significant MANOVA main effects and interaction, univariate analysis of each physiological measure was conducted.

Table 2 contains a summary of the univariate statistics for each physiological measure. For both HR and SC there were significant main effects for Condition and Level of processing as well as significant interaction of Condition x Level. Skin temperature showed a significant Condition effect, and a significant interaction of Condition x Level, but the main effect for Level did not quite reach significance. For EMG, only the main effect for Condition was significant.

Table 1
F Statistics and Probability Levels for MANOVA of
Psychophysiological Reactivity Scores Across Trials

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>P</u>
Within Subjects	1	12060800.0	193.2	.0001
Error	29	62424.3		
Condition	2	1262130.0	140.2	.0001
Error	58	9001.0		
Level	2	111086.0	29.7	.0001
Error	58	3738.4		
Condition x Level	4	65065.0	31.4	.0001
Error	116	2071.7		
Condition x Score	6	894131.0	66.0	.0001
Error	174	13550.4		
Level x Score	6	94308.7	27.8	.0001
Error	174	3396.7		
Condition x Level x Score	12	53853.0	26.0	.0001
Error	348	2066.9		

Table 2

Univariate F Statistics and Probabilities for Each Dependent Variable

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>P</u>
<u>Heart Rate</u>				
Condition	2	12.3	81.9	.0001
Error	58	.15		
Level	2	3.2	27.4	.0001
Error	58	.11		
Condition x Level	4	1.5	37.4	.0001
Error	116	.04		
<u>Skin Conductance</u>				
Condition	2	23010.9	91.4	.0001
Error	58	251.7		
Level	2	2325.8	29.4	.0001
Error	58	79.2		
Condition x Level	4	332.7	28.7	.0001
Error	116	46.4		
<u>Skin Temperature</u>				
Condition	2	.017	5.16	.008
Error	58	.003		
Level	2	.007	2.59	.084 N.S.
Error	58	.003		
Condition x Level	4	.002	3.15	.017
Error	116	.0007		
<u>EMG</u>				
Condition	2	317.1	7.6	.001
Error	58	42.0		
Level	2	2.4	.78	.46 N.S.
Error	58	3.1		
Condition x Level	4	3.2	1.26	.28 N.S.
Error	116	2.5		

Given the significance of the univariate findings, a series of post hoc tests on the obtained means was conducted to determine if the three levels differed during each processing phase. Therefore, each of the three conditions (cue, covert processing, verbalization) was analyzed separately with respect to level of processing and psychophysiological variable.

Table 3 contains a summary of differences among the means, assessed by Duncan's Multiple Range Tests. For HR, the following means were significantly different ($p < .05$): in the cue phase, both PL and HSL were greater than LSL, but did not differ from each other; in the covert processing phase for HR, PL was less than both HSL and LSL, but HSL did not differ from LSL; in the verbalization phase, all three processing levels differed from each other. For both the covert processing and verbalization phases there was an overall increase in HR response with higher levels of processing.

For SC, the Duncan's Multiple Range Test ($p < .05$) yielded the following results: in the cue phase, PL was significantly greater than both HSL and LSL, and HSL did not differ from LSL; in the covert processing phase, both HSL and LSL were greater than PL, but they did not differ from each other; in the verbalization phase, the three levels differed from each other and there was an increase in reactivity with increase in level.

For ST, there was a greater decline in temperature during the HSL of the verbalization phase as compared to the PL or LSL phases, the latter not differing from one another (Duncan Multiple Range Test ($p < .05$)). In the cue and covert processing phases, the three groups did

Table 3

Mean Differences Derived From Duncan's Multiple Range Tests

HR Cue PL = HSL > LSL

Covert Processing HSL = LSL > PL

Verbalization HSL > LSL > PL

SC Cue PL > HSL = LSL

Covert Processing HSL = LSL > PL

Verbalization HSL > LSL > PL

ST Cue PL = HSL = LSL

Covert Processing PL = HSL = LSL

Verbalization HSL > LSL = PL

EMG Verbalization > Covert Processing > Cue (HSL = LSL = PL)

not differ.

Since only the main effect of Condition was significant for EMG, no post hoc analysis of the Level effects was conducted. Analysis of the Condition main effect by the Duncan Multiple Range Test ($p < .05$) indicated that the three conditions differed significantly in EMG responsiveness: Verbalization > Covert Processing > Cue.

Figures 1, 2, and 3 illustrate the pattern of physiological responses for the three processing levels during cue phase (1), covert processing (2) and verbalization (3).

In sum then, the post hoc analyses indicated different psychophysiological response patterns for each of the three levels of processing during each phase of the procedure. In the cue phase, there was greater SC and HR responsiveness to PL processing than to HSL and LSL processing. In the covert processing phase, there was greater SC and HR responsiveness to HSL and LSL processing than to PL processing. In the verbalization phase, there was greater SC and HR responsiveness as the processing level increased (HSL > LSL > PL). ST data for the verbalization phase were congruent with the SC and HR data but, like the EMG data in all phases, otherwise failed to differentiate level of processing.

Relationship of Memory Scores to Physiological Reactivity

Since an important original issue in the study was the relationship between cognitive performance and physiological reactivity, the next logical analysis was a correlation of memory scores of words recalled from the three levels with the relative amounts of physiological activity occurring at each level. A stepwise multiple regression was used to correlate the dependent measures (SC, HR, ST, EMG) with the memory score

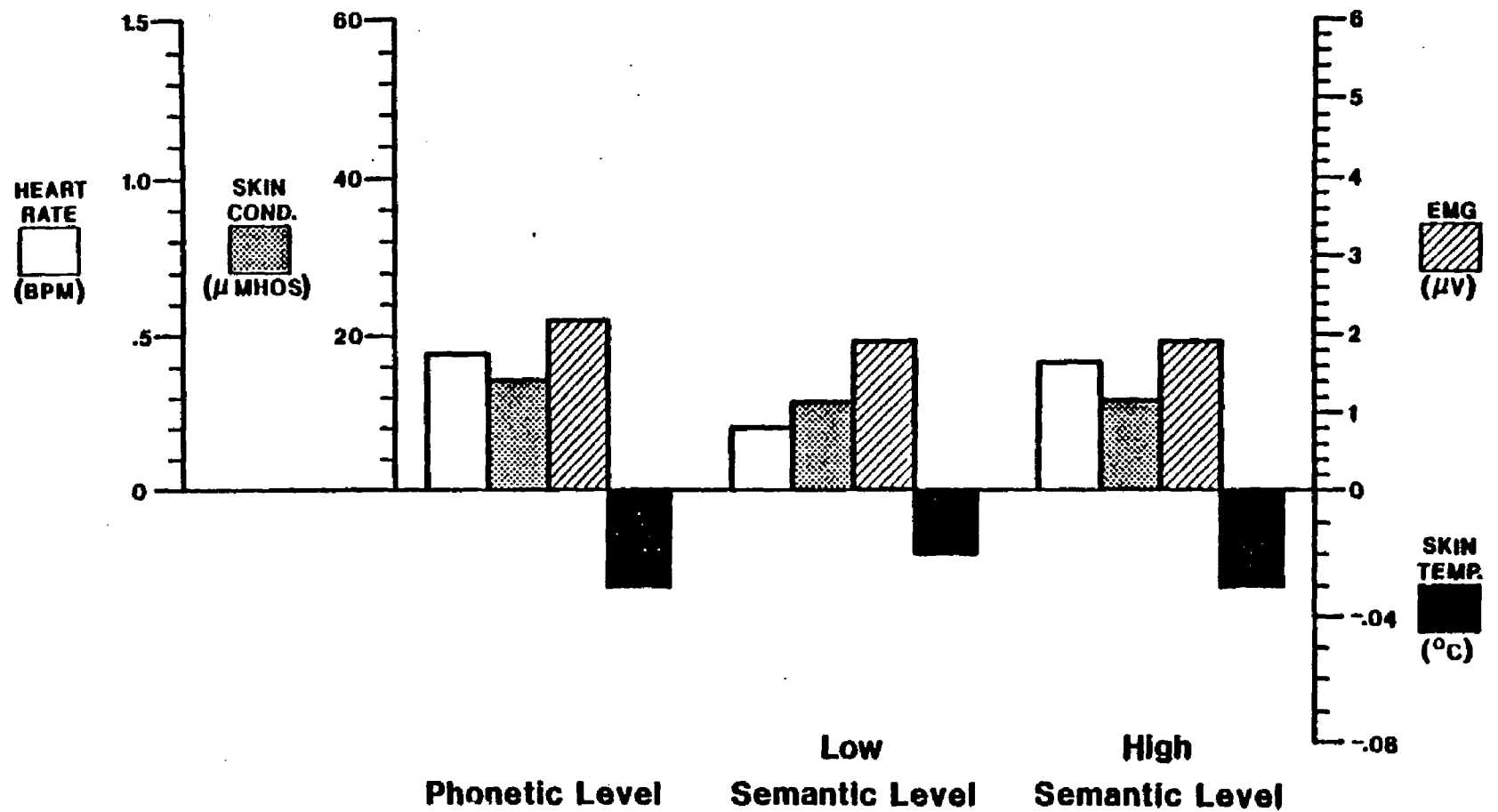


FIGURE 1, PSYCHOPHYSIOLOGICAL RESPONSE PATTERNS DURING THE CUE PHASE

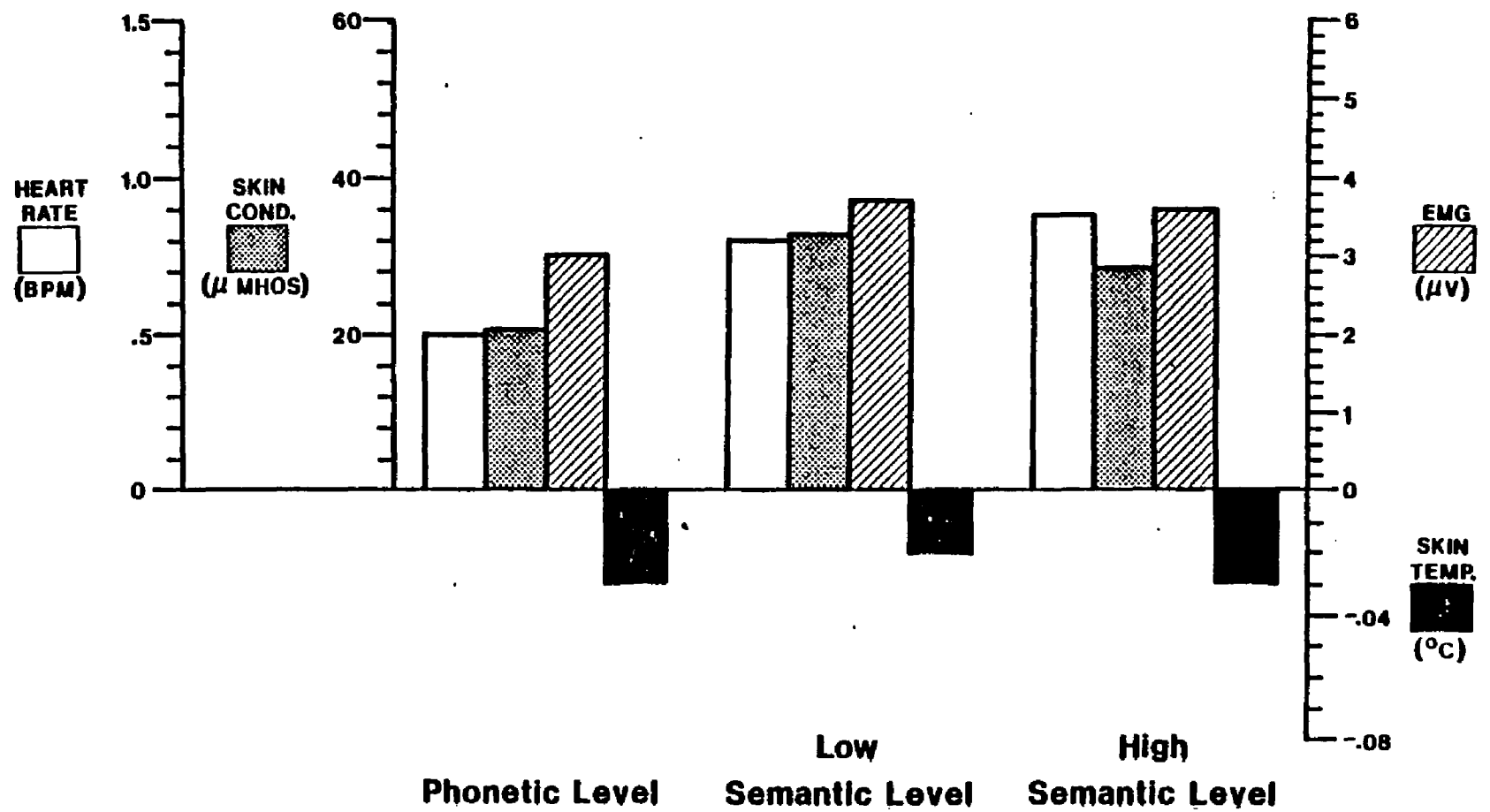


FIGURE 2. PSYCHOPHYSIOLOGICAL RESPONSE PATTERNS DURING COVERT PROCESSING

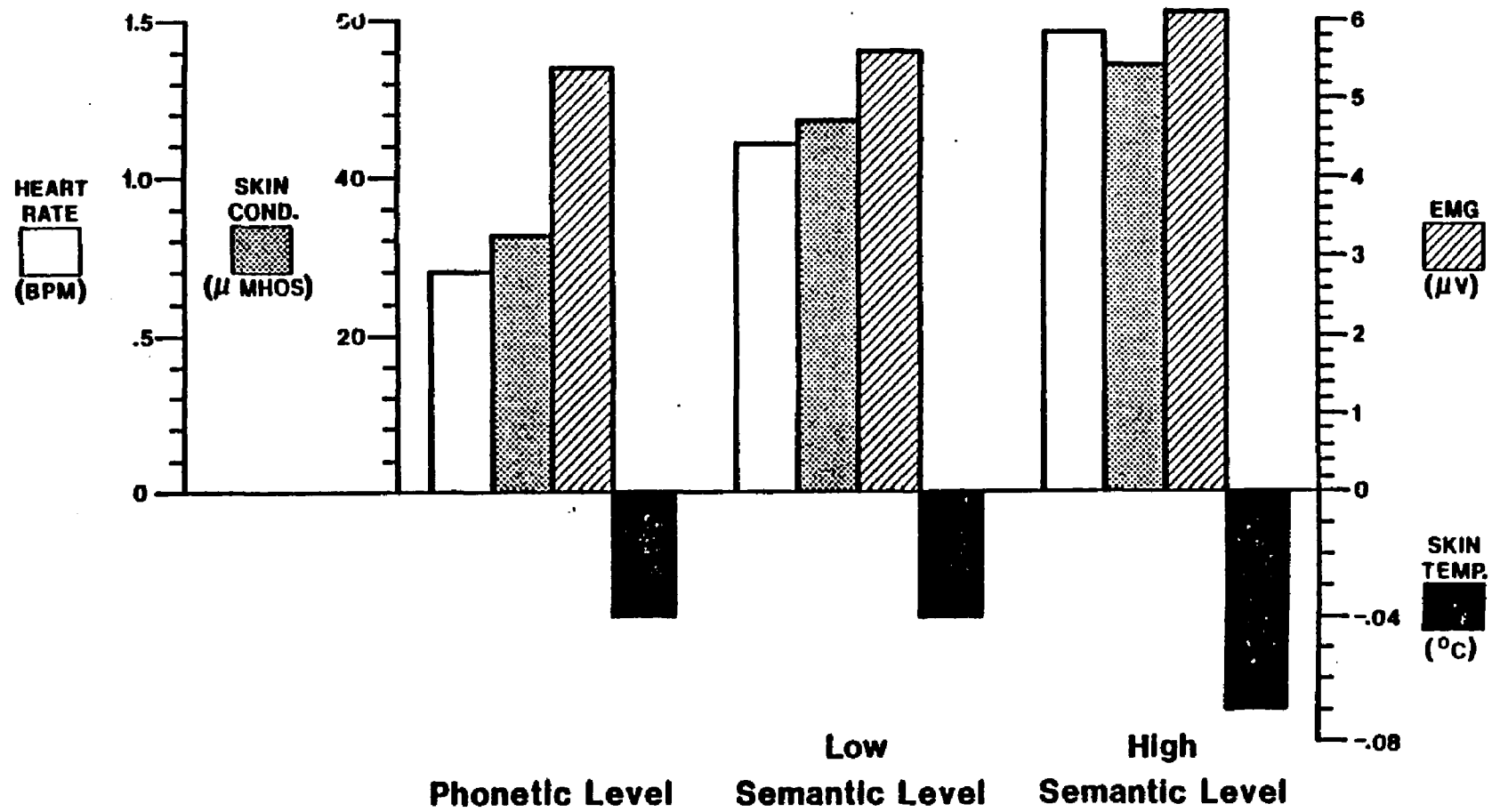


FIGURE 3. PSYCHOPHYSIOLOGICAL RESPONSE PATTERNS DURING THE VERBALIZATION PHASE

(number of recalled words) for each of the levels.

Standardized scores (T-scores) were derived for each subject based on that subject's particular mean response for each psychophysiological measure. This transformation was done to avoid the problem of individual differences in responsiveness (individual response stereotypy) by describing reactivity in each physiological measure in terms of its relationship to the average response level for that measure rather than in absolute terms. Thus, it did not matter that some subjects were primarily HR responders while others were primarily SC responders, etc. since HR and SC were both expressed in comparable terms, deviation from mean responsiveness.

Table 4 contains the multiple correlations and variables extracted by the step-wise regression procedures. As the correlations indicate, there was a statistically significant but unimpressive relationship between physiological reactivity and memory score, i.e., memory scores could not be adequately predicted from a regression equation of psychophysiological variables. The Multiple Correlations varied between .26 and .48, and did not differ significantly across levels of processing. Because of the small values of these correlations, the step-wise regression procedure was able to derive only one variable for most analyses to account for the variance of the correlations. For the cue condition, there were two cases where the tolerance levels were so low as to prohibit any variables from being extracted in this analysis. Generally, HR was the variable extracted in most of the derivations, suggesting that this variable accounted for most of the variance in the limited relationship between physiological reactivity and memory score.

Table 4
Correlations of Memory Score with Standardized Physiological
Measures from Stepwise Multiple Regression
for Each Condition x Level**

	<u>Multiple Correlations</u>	<u>Variables Removed Each Step</u>
Covert Processing x PL	R = .37 *	HR = .37 ⁺ , EMG = .22 [#]
Covert Processing x LSL	R = .36 *	SC = .36, HR = .22
Covert Processing X HSL	R = .23 *	HR = .23
Verbalization x PL	R = .26 *	HR = .26
Verbalization x LSL	R = .37 *	EMG = .37
Verbalization x HSL	R = .41 *	HR = .41

* $p < .05$

** The cue condition failed to meet the minimal tolerance levels, and was not analyzed by the Stepwise procedure.

+Multiple R calculated prior to removing the most influential variable.

#Multiple R calculated after removing the most influential variable.
EMG then becomes the most influential variable.

Physiological Reactivity on Recalled/Non-Recalled Items

A final analysis was conducted to compare the physiological responses occurring during trials that were later recalled versus trials which were not recalled. Overall, 435 of 975 words were recalled across subjects. Table 5 contains the means and standard deviations of recalled versus non-recalled items for the four physiological measures.

There was a significant difference in the physiological reactivity to the two sets of words, as indicated by MANOVA, $F(1,972) = 53.57$, $p < .001$. HR and SC increases were greater for recalled items in both the covert processing and verbalization phases. EMG was greater for Non-recalled items in the covert processing phase. ST did not differ in either condition.

Table 5
Means and (Standard Deviations) for Recalled
and Non-Recalled Words

	Recalled		Not Recalled	
<u>Covert Processing</u>	<u>Mean</u>	<u>SD</u>	<u>Mean</u>	<u>SD</u>
HR (BPM)	.84	(.88)	.60	(.86)
ST ($^{\circ}$ C)	- .02	(.20)	- .02	(.14)
SC (μ mhos)	27.30	(26.70)	23.60	(25.00)
EMG (μ v)	3.50	(6.90)	4.10	(8.80)
<u>Verbalizations</u>				
HR (BPM)	1.34	(1.01)	.81	(.87)
ST ($^{\circ}$ C)	- .05	(.18)	- .04	(.16)
SC (μ mhos)	47.20	(33.80)	38.8	(32.10)
EMG (μ v)	6.50	(10.50)	6.5	(10.90)

DISCUSSION

The results of the present study indicated some interesting relationships among the physiological variables, and the level of processing and the phase of an information processing task. There was also a moderate relationship between physiological reactivity and subsequent memory performance.

Memory performance was analyzed as an important check on the basic assumptions of the levels of processing. It was necessary to demonstrate that different levels of processing were involved in the three information processing tasks entailed in the study (PL, LSL, HSL). The original hypothesis of the levels of processing paradigm (Craik & Lockhart, 1972) predicted a distinction between the orthographic, phonetic and semantic domains which would be reflected in greater incidental recall at the semantic level. The present data, as predicted, indicated significantly greater recall for words presented as part of the semantic tasks than for words presented as part of a phonetic task. Further, there was better memory for words involved in the higher level semantic task than for words presented in the lower level semantic task. As Bloom (1956) indicated, cognitive synthesis requires a number of operations not required in less complex comprehension tasks. The low level semantic task was analogous to the cognitive operation that Bloom described as a comprehension task and the higher level semantic task required the synthesis of the meaning of a word in the solution of the problem. Therefore, the better memory recall at the higher semantic level may point to a level effect within the semantic domain, or an effect of spread of elaboration. (Craik & Tulving, 1975).

The hierarchical nature of the memory performance across the three levels provided a useful framework within which to interpret concomitant changes in physiological reactivity. Overall, physiological reactivity varied according to the level of processing, and also with respect to the phase of information processing (cue, covert processing, verbalization). As already noted, there was greater physiological reactivity on trials involving the semantic tasks during the covert processing and verbalization phases. This finding supports the hypothesis that there is a direct relationship between the levels of processing phenomenon and physiological arousal, greater physiological responsiveness accompanying tasks at the higher processing levels. The differentiation of the phonetic from semantic tasks during the covert processing is particularly important, since these physiological differences cannot be accounted for by the motoric act of verbalization. Based on these findings, two possibilities exist. Either the effect is due to greater anxiety or emotional arousal associated with the semantic task, or to factors more implicit to the nature of the cognitive operations required in the tasks.

The possibility that the physiological effects of levels of processing is due to anxiety, expectancy or other factors involving a more general emotional arousal appears to be negated by the effects noted during the cue phase. The phonetic task cues produced the greatest amount of physiological reactivity. Subjects also reported that the phonetic tasks were the most difficult. Since the cue was designed to inform subjects of the upcoming stimulus, the associated arousal seems to relate to expectancy, and the anticipation of a difficult task. This anticipatory arousal (anxiety), however, does not correspond with the

arousal during the actual information processing phases, since at these phases the phonetic level was not the most arousing. Similarly, the physiological activation to HSL and LSL cues was less than that for the PL cues, but physiological response to HSL and LSL tasks during covert processing was significantly greater than for the PL task. Therefore, the greater physiological reactivity of the semantic tasks at the covert processing phase may relate more specifically to arousal involved in the processing of information than to emotional arousal.

The lack of differentiation between the two semantic levels in the covert processing phase is particularly interesting, since there was a clear differentiation on the verbalization phase. This finding seems to indicate that separation within the semantic domain was related more to differences in the nature of verbal production for the two tasks. As previously noted, there was not a significant difference in the verbalization times for the three task levels, and frontal EMG responses did not differ among levels at the verbalization phase. Thus, the HSL-LSL differentiation during the verbalization phase had to be due to differences in cognitive processing during verbalization rather than motoric output (motor effort) per se. During the covert processing phase, the analysis of the word may be conducted without the components of expressive language functions. During the verbalization phase, the answer that is produced requires the utilization of the association areas of memory, which are involved in the covert processing phase plus the added requirement of language production. Since the semantic levels differed only at the verbalization phase, one can speculate that

verbal production and factors related to expressive language accounted for the spread of elaboration effect (Craik & Tulving, 1975) within the semantic domain. It would seem, therefore, that the HSL task did not involve more complex cognitive processing than the LSL task but that it did involve more overall cognitive processing at a later stage of cognitive-motor processing.

Differentiation of arousal associated with the cue and the two word processing phases was also supported by the occurrence of habituation during the cue phase. Habituation occurred at all three task levels during the cue phase, but failed to occur during the covert processing or verbalization phases at any task level. Habituation to the cues indicates that the arousal associated with task expectancy decreased as subjects became familiar with the tasks. As the novelty of the matching of cue with task was reduced, the physiological reaction to the cue stimulus also decreased. It should be noted, however, that the habituation was evidenced by a decrease in HR acceleration over trials. HR acceleration has most often been associated with emotional arousal rather than with novelty which tends to elicit HR deceleration. It is thus likely that it was a conditioned emotional response to the cue stimulus that was habituated (extinguished) over trials. Further support for this interpretation lies in the fact that PL produced the greatest arousal during the cue phase and it was the PL task which was rated by subjects as (significantly) more difficult than HSL or LSL.

The lack of habituation in the covert processing and verbalization phases may be indicative of a different basis for physiological arousal. The cognitive tasks may have required or induced a physiological response

which corresponded with the demands of the particular task. The relationship between task demands and changes in physiological responses (e.g., heart rate) has been postulated and demonstrated by Sokolov (1963), Lacey (1967) and others.

One of the questions motivating the present study was directed at whether different patterns of physiological activity would be associated with the three levels of processing. Differences in physiological patterning would provide evidence for different physiological mechanisms underlying each processing level. The results do not suggest major differences in physiological patterning according to the level of processing. While there were small differences in the relationship between the variables, generally heart rate, skin conductance and skin temperature all showed greater change scores at the higher processing levels during covert processing and verbalization. Overall, response amplitude rather than pattern seems to be critical in differentiating the three processing levels. The physiological variables tended to covary so that changes in one variable were generally associated with corresponding changes in the other variables. EMG did not covary with the other variables, but it also did not change according to the processing level.

The occurrence of amplitude differences across the three levels suggests the influence of factors such as cognitive effort. While analysis of peripheral physiological systems does not allow for conclusions about underlying central physiological mechanisms, such results may give reason to suspect differences in underlying mechanisms. The present results point to possible quantitative rather than qualitative differences in mechanisms underlying levels of processing phenomena. The amplitude

differences across the three levels is consistent with other studies that have demonstrated a relationship between heart rate acceleration and memory performance (Jennings & Hall, 1980; Yulle & Harrie, 1980).

Yulle and Harre (1980) concluded that the greater physiological responses on trials that were best recalled was related to the amount of cognitive effort, and the maintenance and elaboration of memory. A deceleration of heart rate was also found to be associated with shifts in their taxonomic categories. Thus, a relationship between the direction of heart rate change and the processes of attention and cognitive effort was postulated. Jennings and Hall (1980) reached a similar conclusion, finding that heart rate acceleration was associated with correct performance under conditions involving the processing of previously learned information, while deceleration was associated with correct performance on perceptual processing tasks. The present study involves the processing of common words that are already a part of memory (HSL and LSL), and therefore fits the criteria mentioned by Jennings and Hall for heart rate acceleration. This acceleration may indicate the inaccessibility of the information processing capacity for new information. By becoming less accessible the information processing system may better attend to internal information, rather than external information from the environment. This explanation would correspond with Lacey's (1967) hypothesis about the intake or rejection of new information. The higher level tasks required an increased cognitive effort and a reduction of external stimulation. Therefore there was greater HR acceleration at the higher levels of processing. The fact that skin conductance also showed increases at the higher processing levels indicates that

generalized arousal is also greater. Skin conductance activity is known to increase with cognitive activity. It is less clear that skin conductance relates as directly to the intake or intake rejection of new information.

The hypothesized relationship between physiological responsiveness and memory performance was mildly supported by the multiple correlation analysis of the physiological variables with the recall scores for each processing level. Independent of processing level, there was a moderate relationship between memory and physiological reactivity. The independence of this relationship is important, as it gives further indications that memory covaries with physiological arousal, but that no particular pattern of physiological arousal is associated with any particular level of information processing. Regardless of processing level, individuals showing greater physiological responsiveness tended to have greater recall, indicating that amplitude rather than pattern of response is important to the quality of memory performance. Again, the quantity of physiological reactivity (cognitive effort) seems to account for the observed levels of processing effect rather than differences in the underlying mechanisms.

Interestingly, heart rate was the variable that was extracted most often in the stepwise regressions. Heart rate acceleration was most important in predicting memory performance. This result suggests that the other variables, while greater during the higher processing levels, were not necessarily as important to the later recall of the information. These other variables may reflect the generalized arousal accompanying the greater cognitive effort, rather than the direct

information intake control with which heart rate appears to be associated.

A final analysis, of recalled versus non-recalled items, provided some of the strongest evidence for the importance of physiological reactivity. The recalled items had greater heart rate, skin conductance and skin temperature responses on the antecedent processing tasks than did the non-recalled items. This effect was also independent of the level of processing. The results of both stepwise regression analyses lend support to the argument that the levels of processing effect is related to the amount of cognitive effort involved at the particular level.

Conclusions

One of the original assumptions of the levels of processing paradigm (Craik & Lockhart, 1972) was that the effect was due to a greater quality of encoding occurring at the higher processing levels. Unfortunately, the quality of encoding is difficult to determine through peripheral or any other physiological measurements. Cognitive effort is more easily addressed than encoding within the quantitative constraint of psychophysiology. There seems to be strong evidence in this and other studies for greater cognitive effort at the higher processing levels. The concept of cognitive effort does not preclude the possibility that a more durable memory trace, of greater quality, is produced at the higher levels. However, the concept of cognitive effort does suggest that the quality of the memory trace is related to the extent of processing. In their original formulation, Craik and Lockhart indicated that practice could not account for the effect. While the amount of practice does not

appear to be important to the results of the present study, the intensity of effort as observed in physiological arousal does seem to be important.

The present study also distinguishes between different forms of psychophysiological arousal. The arousal associated with the information processing tasks was clearly different from that associated with the cues preceding them. Information processing was associated with non-habituation psychophysiological responses that increased amplitude with increases in level of processing. Cues were associated with habituating psychophysiological responses, the amplitudes of which were more related to perceived task difficulty than level of processing. The distinction between the various forms of arousal is important in that it suggests that fine components of information processing are reflected in subtle psychophysiological effects. These effects can be separated from each other by constructing an experimental design that allows for converging operations, in the present study by contrasting the three processing levels at different phases of a standard task.

The use of multivariate techniques, including the correlational procedures, enabled an analysis of the relationships among different psychophysiological variables to different phases and levels of information processing. The failure to find specific patterns of psychophysiological activity differentiating or associated with specific levels of processing may provide a significant bit of information about the nature of the cognitive processes. Although the lack of patterning effect does not necessarily mean that the same central physiological systems are involved in all three processing levels, the amplitude differences across levels supports the hypothesis that diff-

erent levels of processing reflect and/or require different degrees of cognitive effort. It is thus possible that levels of processing are essentially quantitatively different rather than qualitatively different, although the latter is by no means ruled out.

The present study tested a cognitive paradigm on a group of normal (non-clinical) college students. A reasonable extension of this research seems to be the application of this design to the study of patients experiencing memory or cognitive difficulties that may be related to dysfunctional attentional, arousal or cognitive mechanisms (e.g., sub-cortical dementia, schizophrenia, hyperkinesia). Its application to such clinical disorders, in providing data about the relationship between physiological arousal and cognitive functioning in these disorders, may cast some light on these etiologies.

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APPENDICES

Appendix 1

List of Stimulus Words

Glass	Phone
Liquor	Gun
Gold	Toy
Clock	Ball
Bed	Jet
Fence	Store
Door	Tree
Horse	Movie
Rocket	Lamp
Jail	Knife
Money	Paper
Table	Music
Street	Coat
Bank	School
Stove	Button
Pen	Flower
Food	Letter
Wheel	Motor
Book	Boat
	Home

Appendix 2

Centroids of Physiological Measures^{*} Averaged
Averaged Across the Three Processing
Levels

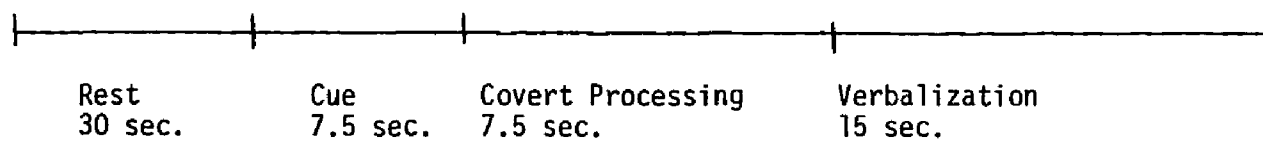
	<u>Cue⁺</u>	<u>Covert Process</u>	<u>Verbalization</u>
<u>Trial</u>			
1	5.5	9.0	12.9
2	5.8	8.6	13.5
3	4.7	7.8	12.3
4	4.2	8.1	12.9
5	4.4	8.6	12.8
6	3.1	7.8	13.1
7	3.1	6.9	11.9
8	2.7	7.7	12.7
9	2.9	7.5	12.6
10	3.6	7.4	12.1
11	3.5	7.3	14.2
12	2.5	6.8	12.6
13	2.4	7.0	14.1

*These scores represent the multivariate centroid required from the four dependent measures (HR, ST, SC, EMG)

+Only significant trial effect on cue condition

APPENDIX 3

FLOWCHART ILLUSTRATING SEQUENCE ON EACH TRIAL



CURRICULUM VITA

NAME: Ronald Alan Cohen

HOME ADDRESS: 653 Milwood Avenue
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WORK ADDRESS: Department of Psychology
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Los Angeles, California 90024

TELEPHONE: Home - (213) 823-1527
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DATE OF BIRTH: July 13, 1955

SOCIAL SECURITY NO.: 145-40-6528

MARITAL STATUS: Single

EDUCATION: Ph.D. Candidate - Clinical Psychology/
Health Psychology, Minor-Behavioral
Neurology, Louisiana State University,
August 1979 - Present

M. S. - Experimental Cognitive Psychology,
University of New Orleans, 1977-
1979

B.S. - Psychology/Pre-Medicine,
Tulane University, 1973-1976

PROFESSIONAL EXPERIENCE: CLINICAL -

Psychology Intern, UCLA-Neuropsychiatric
Institute - June, 1981 - Present. Assign-
ments: Neuropsychological Service, individ-
ual therpay with a variety of disorders
including anorexics and borderline patients;
Affective Disorders Clinic; Seizure Dis-
orders Group; Schizophrenia After Care.
Supervisors: David Wellisch, Jeffrey
Schaeffer.

Psychology Extern, Earl K. Long Hospital -
May, 1980 - May, 1981. Assignments:
Family Medicine and Pediatrics. Assessment
and treatment of psychological/psychophysio-
logical disorders, behavioral medicine,
supervision of graduate students.

PROFESSIONAL
EXPERIENCE (Contd.)

Supervisors: Phillip Brantley, Ph.D.,
Donald Williamson, Ph.D.

Psychology Fellow, Louisiana State
University Counseling Center/Student Health
Center - August, 1979 - Present. Assign-
ments: Individual psychotherapy for
students, Psychological assessment/testing.
Supervisors: Arthur Rosenkrantz, Ph.D.,
Sue Jensen, Ph.D., William Waters, Ph.D.

Associate Supervisor, Tulane University,
Counseling and Testing - August, 1979 -
October, 1980. Assignments: Administra-
tion of standardized tests including GRE,
GMAT and Specialty Board Exams. Supervisor:
J. Mark Pratt, M. S.

Psychological Assistant, Rutgers Community
Mental Health Center, New Brunswick, N.J. -
Summer, 1978. Assignments: Administration
of a token economy in the adolescent
psychiatric unit, patient care, group coun-
seling.

Psychiatric Technician, Coliseum House,
New Orleans, LA. - August, 1976 - February,
1977. Assignments: Co-therapist in in-
patient adult group psychotherapy, patient
care in milieu setting. Supervisor:
Sue White, R. N.

Adolescent Counselor, Boy's Club of New
Orleans - August, 1974 - February, 1975.
Supervisor: Bob Ford

CONSULTING -

Consultation-Liaison Service, Neuropsychi-
atric Institute - June, 1981 - Present.
Assignments: Consultation with Medical
Residents and Neurology and Internal Med-
icine Services. A wide variety of duties
including assessment of psychological/psycho-
physiological factors in medical patients.

Psychology consultant, Earl K. Long Hospital -
May, 1980 - May, 1981. Assignment: Con-
sultation with Medical Residents on psycho-
logical problems encountered in the

PROFESSIONAL
EXPERIENCE (Contd.)

in-patients of the hospital. Supervisor:
Phillip Brantley, Ph.D.

Psychological Consultant, Belle Chasse
State School - August, 1978 - August, 1979.
Assignments: Pre-admission diagnostics
and screening of mentally retarded and
emotionally disturbed adults and children
for placement in the residential program,
aided in developing a behavior modification
program. Supervisors: Charles Hill, Ph.D.,
Caroline Fisher, Ph.D.

TEACHING -

Graduate Teaching Assistant, Louisiana
State University - August, 1979 - May, 1980.
Assignments: Assisted professor in class
preparation and instruction of graduate and
undergraduate classes. Supervisor: Robert
Coon, Ph.D.

Teaching Assistant, University of New
Orleans - August, 1977 - May, 1978.
Assignments: Lab Instructor for experi-
mental psychology class. Supervisors:
Seth Kunen, Ph.D., James May, Ph.D.

RESEARCH -

Neuropsychiatric Institute - June, 1981 -
Present. Assignments: Research on
psychophysiological concomitants of cog-
nitive processes; evoked potential appli-
cations in neuropsychological assessment;
behavior therapy in anorexia. Supervisors:
David Shapiro, Ph.D., Gerald Tarlow, Ph.D.

Research Assistant, Louisiana State Uni-
versity - August, 1980- May, 1981.
Assignments: Research on psychophysio-
logical response specificity and stereo-
typy in clinical and normal population,
psychometric evaluation of response stereo-
typy using factor analytic procedures.
Supervisors: William Waters, Ph.D.,
Donald Williamson, Ph.D.

Independent Research, Louisiana State
University - March, 1980 - August, 1980.

PROFESSIONAL
EXPERIENCE (Contd.)

Assignments: Treatment of muscle contraction and migraine headache clients using relaxation and stress management.
Supervisor: Donald Williamson, Ph.D.

Research Assistant, University of New Orleans - August, 1977 - May, 1978.
Assignments: Research in hemispheric dominance, information processing and visual masking, received some training in averaged evoked potential in the visual system, study of blood pressure biofeedback with hypertensive and normal subjects.
Supervisors: Seth Kunen, Ph.D., James May, Ph.D.

Research Assistant, Psychology, Tulane University - August, 1975 - May, 1976.
Assignment Research in human memory, verbal learning and cognition. Supervisor: Chizuko Izawa, Ph.D.

Biomedical Research, Bio-Dynamics Corporation, E. Millstone, N. J. - Summer, 1976.
Assignment: Behavioral and anatomical study of laboratory animals in toxicology study. Supervisor: Robert Bennington.

HONORS:

N.I.M.H. Fellowship, Louisiana State University, 1979-1980.

Graduation Honors in Psychology, Tulane University, May, 1976.

National Merit Scholarship, 1973-1976. Skill Corporation.

PUBLICATIONS:

Cohen, R. & Izawa, C. The effects of phonetic symbolism in paired associate learning. Bulletin of the Psychonomic Society, 1977.

Kunen, S. & Cohen, R. A levels of processing analysis of Bloom's Taxonomy. Journal of Educational Psychology, April, 1981.

MANUSCRIPTS IN PRESS:

Williamson, D., Cohen, R., Pratt, M., Jarrell, P. & Monguillot, J. A controlled evaluation of a self-help and a therapist-assisted program for migraine and muscle contraction headache.

Cohen, R., Williamson, D., Waters, W. & Pratt, M. Psychophysiological response specificity and stereotypy for migraine and muscle contraction headache.

Granberry, S., Williamson, D. & Cohen, R. The establishment of an empirical classification system for headache diagnosis.

Cohen, R. & Tuma, J. A survey and evaluation of pediatric psychology training program.

PAPERS PRESENTED:

Williamson, D., Cohen, R., Pratt, M., Jarrell, P. & Monguillot, J. A controlled evaluation of a self-help and a therapist-assisted program for migraine and muscle contraction headache. American Association of Behavior Therapy, Toronto, November, 1981.

Granberry, S., Williamson, D. & Cohen, R. The establishment of an empirical classification system for headache diagnosis. American Association of Behavior Therapy, Toronto; November, 1981.

Cohen, R., Williamson, D., Waters, W. & Pratt, M. Psychophysiological response specificity and stereotypy for migraine and muscle contraction headache. American Association of Behavior Therapy, Toronto; November, 1981.

MANUSCRIPTS IN PREPARATION: Pratt, M. & Cohen, R. Depression and the response to stress in headache populations.

Cohen, R. & Coon, R. Effects of situational saliency on the development of social cognition.

MANUSCRIPTS IN
PREPARATION (contd.)

Waters, W. & Cohen, R. Presently involved in a research project studying response specificity and stereotypy across various clinical populations. An attempt is being made to develop a self report rating form via factor analytic procedures which will be useful in predicting subjects' response patterns.

RESEARCH INTEREST:

Research is in progress in which Averaged Evoked Potential measures will be employed. Investigation of information processing variables, such as selective attention, will be studied with respect to schizophrenia, toxic drug effects, and gerontology.

REFERENCES:

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Bernard Jensen, Ph.D., Psychology
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William Waters, Ph.D., Clinical Director
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David Wellisch, Ph.D., Psychology
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Louisiana State University
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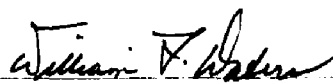
EXAMINATION AND THESIS REPORT

Candidate: Ronald A. Cohen

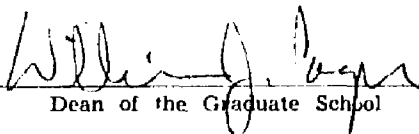
Major Field: Psychology

Title of Thesis: Psychophysiological Concomitants of Levels of Cognitive Processing

Approved:

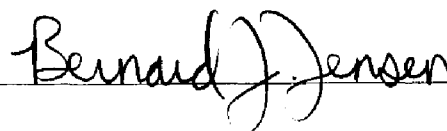
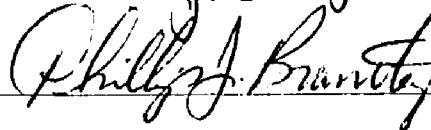
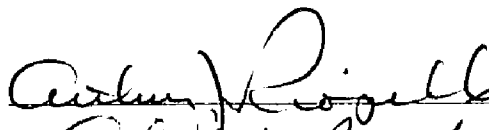


Major Professor and Chairman



Dean of the Graduate School

EXAMINING COMMITTEE:



Date of Examination:

July 19, 1982